

# FIVE COLLEGE RADIO ASTRONOMY OBSERVATORY

619 Lederle Graduate Research Center, University of Massachusetts, Amherst, MA 01003

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## BOUNDARY CONDITIONS FOR THE PALEOENVIRONMENT: CHEMICAL AND PHYSICAL PROCESSES IN THE PRE-SOLAR NEBULA

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Principal Investigator: William M. Irvine

Co-Principal Investigator: F. Peter Schloerb

### Current Research

In observations with the NRAO 12m telescope at Kitt Peak, Arizona, Irvine, graduate student D. McGonagle, and colleagues from Japan have detected a new interstellar radical,  $\text{CH}_2\text{N}$ . This identification is important for the study of hydrogenation processes in the interstellar medium. In particular, although the abundance of hydrogen is some four orders of magnitude higher than that of other reactive elements in this environment, many organic molecules in quiescent clouds are very unsaturated. This is a consequence of activation barriers which cannot be overcome at the temperatures of cold clouds, even when such reactions are energetically allowed. The hydrogenation series based on the cyanide radical ( $\text{H}_n\text{CN}$ ) has had four members previously detected in the interstellar medium:  $\text{CN}$  ( $n=0$ ),  $\text{HCN}$  ( $n=1$ ),  $\text{CH}_2\text{CN}$  ( $n=2$ ), and  $\text{CH}_3\text{NH}_2$  ( $n=3$ ). The recent

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determination of the rotational spectrum of the  $\text{CH}_2\text{N}$  radical through microwave spectroscopy in Japan has made possible a search for this species. In addition to its potential importance for interstellar chemistry, the  $\text{CH}_2\text{N}$  radical has been proposed as a reaction intermediate for HCN production in the atmosphere of Jupiter, and as a possible species in the expanding envelopes of oxygen-rich evolved stars. We detected  $\text{CH}_2\text{N}$  in the cold cloud TMC-1 (Ohishi et al. 1993), where the abundance seems to be some three orders of magnitude lower than that of HCN. A tentative detection was made in the Galactic Center molecular cloud Sgr B2. To our knowledge, there are no predicted abundances of  $\text{CH}_2\text{N}$  from models of interstellar chemistry.

Upper limits on the abundance of molecular species are also important to interstellar chemistry. Together with colleagues from Sweden, Irvine searched for the ion  $\text{PO}^+$  in the interstellar medium using the Swedish-European Submillimeter Telescope in Chile. No definitive detection was made, although the spectral regions examined are confused because of the presence of many lines produced by other molecular constituents. A search for the protonated formaldehyde ion,  $\text{H}_2\text{COH}^+$ , has also been made. This search was carried out at the Five College Radio Astronomy Observatory (FCRAO), operated by the University of Massachusetts. Former UMass student Y. Minh (now at the Korean Astronomical Observatory), Irvine, and McGonagle find an upper limit on  $\text{H}_2\text{COH}^+$  which suggests that the abundance of formaldehyde in the region studied is less than had previously been thought.

D. McGonagle is continuing his study of interstellar nitrogen chemistry, with observations of the  $J=3/2-1/2$  transition of nitrogen sulfide being made at the NRAO 12m telescope. The results for dark clouds indicate that NS is extended in both TMC-1 and L134N. The distribution in TMC-1 is more similar to that of  $\text{C}^{18}\text{O}$  and methanol than to that of the cyanopolyynes or ammonia (both of the latter species have peaks in their distribution indicating abundance gradients along the TMC-1 ridge). The same transition was also detected in several giant molecular clouds. Using the data from the two rotational

transitions and from a third transition detected in Orion KL as part of the 2mm spectral survey, the excitation and abundance of NS are being determined in a variety of environments.

McGonagle and L. Ziurys (Arizona State University) are continuing their analysis of data taken in the 2mm wavelength region toward the Orion molecular cloud. This is the first spectral survey of an interstellar cloud undertaken in this wavelength region. Nearly 500 emission lines have been detected, a significant fraction of which are as yet unidentified.

The major chemical study of giant molecular cloud cores is continuing. Thirty-three transitions for 21 molecular species have been mapped over extended regions of the clouds Orion A, Ceph A, and M17 in order to distinguish gradients in chemical abundances from variations in physical properties. The Orion data have been subjected to a principal component analysis, an interesting result of which is that the data are well described by a small number of principal components, three to five. The observed molecules divide into groups in terms of their distribution in the cloud. Similar analyses are underway for Ceph A and M17. The data, supplemented by observations at other wavelengths, are also being used to construct maps of kinetic temperature and density in these regions.

Postdoctoral Research Associate H. Ungerechts gave a review talk on the chemical study of giant molecular clouds described above at the Second Cologne Symposium on the Physics and Chemistry of Molecular Clouds, held in Zermatt, Switzerland, in September, 1993. Irvine gave a review talk on interstellar chemistry at the Gordon Conference on "Origin of Solar Systems" in July, 1993. Irvine also prepared material on progress during the last three years in the study of the cosmic evolution of the biogenic elements and compounds on behalf of Commission 51 of the International Astronomical Union, in preparation for the General Assembly of the IAU to be held next year.

Papers supported by this grant and published during the period of this report:

1. "The Relative Abundances of the A and E Symmetry Species of CH<sub>3</sub>CN in the Cold Cloud TMC-1", Minh, Y.C., Irvine, W.M., and Ohishi, M., Astron. Astrophys., **267**, 229 (1993).
2. "Chemistry of the Cosmos", Irvine, W.M., in Frontiers of Life, ed. J. Tran Thanh Van et al., Editions Frontieres, France, pp. 263-290, 1992.
3. "Interferometric Observations for Oxygen-Containing Organic Molecules toward Ori KL", Minh, Y.C., Ohishi, M., Roh, D.G., Ishiguro, M., and Irvine, W.M., Ap. J., **411**, 773, 1993.
4. "Recent Developments in Interstellar Chemistry", McGonagle, D. and Irvine, W.M., in Recent Developments in Millimeter-Wave and Infrared Astronomy, ed. S.H. Cho and H.S. Chung, Korea Astronomy Observatory (Daejon, Korea), pp. 65-76, 1993.

Research supported by this grant currently in press:

1. "Organic Molecules in the Gas Phase of Dense Interstellar Clouds", Irvine, W.M., Adv. Space Res., in press (1993).
2. "Astronomy at Millimeter Wavelengths", Irvine, W.M., Schloerb, F.P., Schneider, S.E., and Snell, R.L., in Proc. INAOE Jubilee Symp., (1993).
3. "Observations of C<sub>3</sub>H<sub>2</sub> (2<sub>12</sub>-1<sub>01</sub>) toward the Sagittarius A Molecular Cloud", Lee, C.W., Minh, Y.C., and Irvine, W.M., J. Korean Ast. Soc., in press, 1993.
4. "Nitrogen Sulfide in Cold, Dark Clouds", McGonagle, D., Irvine, W.M., and Ohishi, M., Ap. J., in press, 1993.
5. "Observations of Small Nitrogen-Containing Molecules in Dark Clouds: NO, NS and H<sub>2</sub>CN", Irvine, W., McGonagle, D., Ohishi, M., Yamamoto, S., and Saito, S., in Proc. Second Zermatt Conf. Interstellar Clouds, ed. J. Stutzki, in press.
6. "Detection of a New Interstellar Molecule CH<sub>2</sub>N", Ohishi, M., Yamamoto, S., Saito, S., McGonagle, D., and Irvine, W.M., to be submitted.
7. "Search for H<sub>2</sub>COH<sup>+</sup> and H<sub>2</sub><sup>13</sup>CO in Dense Interstellar Molecular Clouds", Minh, Y.C., Irvine, W.M., and McGonagle, D., J. Korean Ast. Soc., to be submitted.

### Future Plans

A. Eschenmoser has suggested that the molecule oxiranecarbonitrile may play a key role in prebiological molecular evolution. The rotational spectrum of oxiranecarbonitrile is

being studied by A. Bauder in Switzerland. We plan a collaboration with Drs. Bauder, Eschenmoser, and G. Arrhenius to carry out a search for interstellar oxiranecarbonitrile.

We hope to carry out a separate search for interstellar  $\text{NH}_2$ , using the facilities of the James Clerk Maxwell Telescope in Hawaii.  $\text{NH}_2$  is a key intermediary in the production of  $\text{NH}_3$ , and its abundance would provide direct evidence concerning the relative importance of gas phase and surface chemistry in the production of fully saturated molecules like ammonia.

McGonagle will continue his study of interstellar nitrogen chemistry. An interesting result that has come as a byproduct of the detection of NS in cold clouds is the discovery of an unidentified feature in L134N, the first such unidentified line in this source.

Observations are planned at various harmonics and subharmonics of the U-line frequency to see if other transitions with the same carrier can be found. McGonagle is also continuing his analysis of the abundance of NS in regions of active star formation in the Galaxy, where the temperatures are higher than those in cold quiescent clouds. His work on the 2mm survey of the Orion cloud is part of his general study of nitrogen chemistry, since several nitrogen-containing species have transitions in this spectral band.

The major FCRAO project for chemical mapping of molecular clouds in many molecular species will continue. The principal component analysis thus far applied to Orion will be extended to M17 and Ceph A to see if the differences in distribution among different classes of molecular species are a general property of interstellar clouds. Comparisons with chemical models will also be made to seek direct evidence for varying physical conditions producing chemical abundance gradients. The completion of a new spectrometer at FCRAO will allow these studies to be extended to the cold, dark clouds in the Galaxy, such as TMC-1 and L134N. These cold clouds lack embedded energetic objects and are thus ideal testing grounds for models of ion-molecule chemistry.

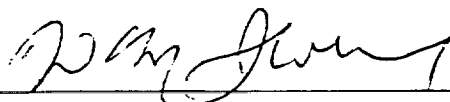
Together with colleagues from Korea, Irvine is studying molecular abundances in the so-called "cirrus clouds" detected by the IRAS satellite. The nature of these clouds is not

well determined, but millimeter wavelength observations can be used to establish the gas density and temperature as well as composition.

In observations of cold, dark clouds such as TMC-1 and L134N, chemical gradients have been found which may be due to variations in the gas phase carbon-to-oxygen ratio, which might in turn arise from differential depletion of water onto interstellar grains. In order to analyze these trends more carefully, Irvine and colleagues from Japan and Korea are planning high spectral resolution observations of CS and CO toward these regions, since chemical models indicate that CS forms preferentially in an excess carbon environment while SO should be indicative of an environment with excess oxygen.

#### Personnel

H. Ungerechts has completed his tenure as a Postdoctoral Research Associate. Dr. Preethi Pratap has been hired in his place. She received her Ph.D. in astronomy from the University of Illinois working on problems of interstellar chemistry, and subsequently has completed a postdoctoral associateship at the Center for Astrophysics.



William M. Irvine  
Principal Investigator



F. Peter Schloerb  
Co-Principal Investigator

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